Study of Blockage Effects on Scouring Pattern Downstream of Box Culverts

By

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To

BIHE teachers

who sacrifice their lives to spread the knowledge

and to

Pouyan

for his ceaseless support and love.

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

Culverts are locations in water courses where a constriction in the water occurs and therefore where blockage of some type is likely to occur. Blockage of culverts commonly occurs during flood events. When a culvert is partially blocked at the inlet, the flow structure in the barrel and at the outlet will change and consequently may result in the failure of the culvert. Despite this, the impacts of blockage on culvert hydraulics and downstream waterways have not received consideration in the literature. The purpose of this study is to mitigate this deficiency by reporting on an investigation into scouring at the outlet of partially blocked culverts.

The aims of this study can be categorised as:

- to investigate the effects of blockage on scour geometry and to develop predictive equations;
- to study the flow structure at the outlet of partially blocked culverts and compare it with a non-blocked culvert to explain the previous findings;
- to conduct the experiments in unsteady flow conditions which are more similar to flood events to validate the general findings

To achieve these aims experimental tests were conducted under steady flow to investigate a relationship between the maximum scour extents, blockage ratio of the culvert and the flow characteristics. Both non-blocked and partially blocked conditions were considered. Consideration of the results obtained showed that the scoured area and maximum scour depth increased with partially blocked culverts conditions compared with equivalent non-blocked culverts. Because complete protection against scour is too expensive, generally, the maximum scour depth of the

scour hole has to be predicted to minimize the risk of failure. Therefore, empirical equations were developed to predict the maximum scour depth, length and width at the outlet of blocked culverts.

In the next stage and to have a better understanding of the turbulent flow conditions at the outlet of a partially blocked culvert an experimental program was designed to measure the longitudinal, lateral and vertical velocity components through the culvert barrel centreline and at the outlet. Tests were conducted in both non-blocked and partially blocked condition. Based on that, the turbulent flow characteristics such as turbulence intensity, turbulent kinetic energy and Reynolds shear stress were obtained for each condition. Results showed that the turbulent flow characteristics in the partially blocked condition are significantly different in the barrel and at the outlet compared to a non-blocked condition of the same discharge.

As the final step of this study, a test program was conducted under unsteady conditions in partially blocked and non-blocked culverts. The results were compared with previous results of steady tests and showed an agreement with previous steady flow tests.

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List of Publications Related to This Thesis

Journal Articles

1. SOROURIAN, S., KESHAVARZI, A., BALL, J. & SAMALI, B. 2013. Study of Blockage Effect on Scouring Pattern Downstream of a Box Culvert under Unsteady Flow. *Australian Journal of Water Resources*. Engineers Australia, Vol.18, Issue 2,180-190.
2. SOROURIAN, S., KESHAVARZI, A., BALL, J. 2015. Scour at partially blocked box-culverts under steady flow. *Proceedings of Institution of Civil Engineers- Water Management,* Thomas Telford Ltd, Published online 28 October 2015.

Conference Papers

1. SOROURIAN, S., KESHAVARZI, A., BALL, J. 2015. Turbulent Flow Characteristics at the Outlet of a Partially Blocked Box Culvert. Proceedings of 36^{th} International Association for Hydro-environment Research World Congress, 28 June-3 July 2015, Delft, Netherlands.
2. SOROURIAN, S., KESHAVARZI, A., BALL, J. & SAMALI, B. 2014. Location of the maximum scouring depth at the outlet of partially-blocked and non-blocked box culvert. Proceedings of 7^{th} International Conference on Fluvial Hydraulics, River Flow 2014. CRC Press, 1475-1480.
3. SOROURIAN, S., KESHAVARZI, A., BALL, J. & SAMALI, B. 2014. Prediction of Scouring Depth at the Outlet of Partially Blocked Box Culvert.

In: World Environmental and Water Resources Congress 1-5 June 2014 Portland, Oregon. American Society of Civil Engineers, 1352-1361.

4. SOROURIAN, S., KESHAVARZI, A., BALL, J. & SAMALI, B. 2013. Study of Blockage Effect on Scouring Pattern Downstream of a Box Culvert under Unsteady Flow. 35th International Association for Hydro-environment Research World Congress World Congress. Chengdu, China.
5. SOROURIAN, S., KESHAVARZI, A., SAMALI, B. & BALL, J. 2012. Study of blockage effect on scouring pattern downstream of a box culvert. In: SAMALI, B., ATTARD, M. M. & SONG, C., eds. Proceedings of the 22nd Australian Conference on the Mechanics of Structures and Materials, 2012 Sydney. CRC Press, Balkema, 741-744.

Table of Contents

List of Tables

List of Figures

List of Notations

A cross section area of the culvert outlet

A_B blockage area at culvert inlet

A_F flow area at culvert inlet

A_s scoured area

B blockage ratio

C_c sediment coefficient of curvature

C_h coefficient for culvert drop

C_s coefficient for culvert slop

C_u sediment coefficient of uniformity

D circular culvert diameter

DI discharge intensity

d_0 outlet diameter in circular-shape culverts

d_m effective grain size

d_s scour depth

d_{sm} maximum scour depth

$d_{sm(t=i)}$ maximum scour depth at time $i(i = 10,20,..110)$ of the test

$d_{s0(t=i)}$ Scour depth at culvert outlet at time $i(i = 10,20,..110)$ of the test

d_{50} median grain size of bed material

g gravity acceleration

F_d densimetric Froude number

F_{d95} modified densimetric Froude number

F_r flow Froude number

F_{rp} prototype Froude number

F_{rm} model Froude number

H culvert height

H_v velocity head

H_w headwater depth

h_B height of blockage plate

h_d depth of water at culvert outlet

h_e entrance loss

h_f friction loss

h_t tail water depth

h_u upstream depth of water

KE_x kinetic energy in x direction

KE_y kinetic energy in y direction

KE_z	kinetic energy in z direction
L	culvert length
L_t	total scour length
Q	flow rate
R^2	coefficient of correlation
R_H	Hydraulic radius
RSS	Reynolds shear stress
S_0	bed slope
S	culvert slope
S_E	standard error of estimate
S_f	energy gradient
TI_x	turbulence intensity in x direction
TI_y	turbulence intensity in y direction
TI_z	turbulence intensity in z direction
t	time of experiment
u	mean flow velocity
u_m	flow velocity in the model
u_p	flow velocity in prototype

u^* shear velocity

u^*_c shear velocity at initiation of motion

v_x flow velocity in x direction

v_y flow velocity in y direction

v_z flow velocity in z direction

v'_x turbulent fluctuations of the flow velocity in y direction

v'_y turbulent fluctuations of the flow velocity in x direction

v'_z turbulent fluctuations of the flow velocity in z direction

W culvert width

W_c half width of culvert

W_{sm} maximum scour width

X horizontal axis (flow direction)

X_m length characteristic in model

X_p length characteristic in prototype

x_s horizontal distance from the outlet

x_{sm} location of maximum scour depth along horizontal axis

$x_{sm(t=i)}$ location of maximum scour ole in horizontal axis at time i of the test

y_s width of scour hole at any location along y axis

z depth of water from culvert invert

λ scaling ratio

ρ water density

ρ_s sediment density

$\boldsymbol{\sigma}_g$ sediment geometric standard deviation

List of Notation Used by Other Researchers

b depth of tailwater (in Figure 2-5)

h^*_{100} cube root of the volume of scour after 100 hours (in Figure2-5)

H_b height of the drop (in Figure 2-5)

E_0 energy of the jet at the tail water surface (in Figure 2-5)

W_m mean fall velocity (in Figure 2-5)

B width of the flow (in Figure2-6)

V_m mean velocity (in Figure2-6)

$\nabla\gamma_{st}$ Buoyant specific weight of bed material (in Figure2-6)

H_0 inside height of culvert (in Figure2-7)

W_0 Inside width of culvert (in Figure2-7)